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Glueball Interpretation of $\xi(2230)$

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Abstract

On the basis of the results of $\xi(2230) \to \pi^+\pi^-, p\bar{p}$ and $K\bar{K}$, measured by the BES Collaboration in radiative J/ψ decays, combined with the upper limit of Br($\xi \to p\bar{p}$)Br($\xi \to K\bar{K}$), measured by PS185 experiment, we argue that the distinctive properties of $\xi(2230)$, the flavor-symmetric decays and the narrow partial decay widths to $\pi\pi$ and $K\bar{K}$ as well as its copious production in radiative J/ψ decay, would strongly favor the glueball interpretation of $\xi(2230)$.

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BES Collaboration have reported their new results about $\xi(2230)$ [1]. They confirmed the existence of $\xi(2230)$ in the decays J/$\psi \to \gamma K\bar{K}$ and they also found two new non-strange decay modes $\xi \to p\bar{p}$ and $\pi^+\pi^-$. The preliminary results of the mass, width and branching ratios of $\xi(2230)$ measured by BES are the following[1]: In J/$\psi \to \gamma\pi^+\pi^-$ process, $M_\xi = (2235^+_-4^+_-6)$MeV, $\Gamma_\xi = (19^{+13+}_{-11-}12)MeV, Br(J/\psi \to \gamma\xi)$ Br$(\xi \to \pi^+\pi^-) = (5.6^{+1.8+}_{-1.6-}1.4) \times 10^{-5}$. In J/$\psi \to \gamma K^+K^-$ process, $M_\xi = (2230^{+6+}_{-7-}12)$MeV, $\Gamma_\xi = (20^{+20+}_{-15-}12)MeV, Br(J/\psi \to \gamma\xi)$ Br$(\xi \to K^+K^-) = (3.3^{+1.6+}_{-1.3-}1.1) \times 10^{-5}$. In J/$\psi \to \gamma p\bar{p}$ process, $M_\xi = (2235^+_-4^+_-5)$MeV, $\Gamma_\xi = (15^{+12+}_{-9-}9)MeV, Br(J/\psi \to \gamma\xi)Br(\xi \to p\bar{p}) = (1.5^{+0.6+}_{-0.5-}0.5) \times 10^{-5}$.

Previous theoretical interpretations of $\xi(2230)$ included identification as a high spin $s\bar{s}$ state[2], a multiquark state (such as a 4-quark state[3,4], a $\Lambda\bar{\Lambda}$ bound state[5], a neutral color scalar bound state [6], etc.), a hybrid state[3,7] and a glueball[8]. Since Mark III Collaboration only found strange decay modes of $\xi(2230)$[9], the $s\bar{s}$ interpretation seemed plausible and the glueball interpretation would be ruled out. The new discovery of BES experiments on non-strange decay modes provides us with extremly important clue so that the nature of $\xi(2230)$ will become clear.

Compared with other mesons, $\xi(2230)$ has many distinctive properties: (1) flavor-symmtric decays. With the phase space factors removed, it can be found that the probability of $\xi \to \pi^+\pi^-$

is of the same order as that of $\xi \to K^+K^-$. (2) Copiously production in radiative J/ψ decays[10]. From the upper limit[11,12] Br($\xi \to p\bar{p}$) Br($\xi \to K\bar{K}$) $< 1 \times 10^{-4}$, where $K\bar{K}$ include all kaon pairs, and the BES's results, one can easily estimated that lower limit of Br($J/\psi \to \gamma\xi$) is 3×10^{-3}. (3) Narrow width. Both Mark III's results and BES's results show that the width of $\xi(2230)$ is only about 20 MeV[1,9]. In this paper, we use Γ_ξ= 20 MeV. From (2)(3), it can also be easily estimated that Br($\xi \to K^+K^-$) and Br($\xi \to \pi^+\pi^-$) are smaller than 2%, so the partial width $\Gamma_{\pi^+\pi^-}$ and $\Gamma_{K^+K^-}$ are smaller than 400 keV[10].

Although the knowledge about $\xi(2230)$ is still limited by the experimental facts, the features of $\xi(2230)$ we have known so far are so special and so clear that they would make it possible for us to understand the nature of $\xi(2230)$.

For an $s\bar{s}$ meson, it should not show so good flavor-symmetric decay behavior and the $\Gamma_{K^+K^-}$ would not be so narrow since its decay to $K\bar{K}$ is OZI allowed. The resonance aroud 2.2 GeV found by LASS Collaboration[13] in $Kp \to \Lambda K\bar{K}$ process may be different from $\xi(2230)$ since it is produced in different mechanism from the radiative J/ψ decay and its mass, width and J^{PC} are different from the BES's results[1,14]. More generally, considering all conventional $q\bar{q}$ mesons, including $(u\bar{u} + d\bar{d})$, $s\bar{s}$ or their admixtures, it is worth noticing that there are not any other particles showing such properties[12] as ξ except for the particles with pure OZI suppressed decay modes such as J/ψ, χ_{c0}, χ_{c2}, etc. The typical width for conventional $q\bar{q}$ mesons with OZI allowed decay modes is about 100$-$200 MeV if all other quantum numbers are allowed and the phase space is not too small, especially its partial width of certain main decay modes must be of order 10-100 MeV. E.g., for the $P-$wave J^{PC}=2^{++} mesons, the $f_2(1270)$, which is mainly a $(u\bar{u}+d\bar{d})$ state, has a partial width of about 150 MeV to $\pi\pi$, while the $f_2'(1525)$, which is mainly an $s\bar{s}$ state, has a partial decay width of about 50 MeV to $K\bar{K}$ [12]. For the $F-$wave mesons, based on some quark model calculation it was argued[2] that if $\xi(2230)$ were an $^3F_2$ or $^3F_4$ $s\bar{s}$ state, its decay to $K\bar{K}$ could be suppressed by the L = 3 centrifugal barrier and consequently the decay width to $K\bar{K}$ could be lowered to 20$-$30 MeV, but cannot be as small as the order of several hundreds keV. On the other hand, the $f_4(2050)$, which is a $(u\bar{u}+d\bar{d})$ dominant $^3F_4$ state, has an observed total width of 200 MeV and a partial decay width of 30 MeV to $\pi\pi$[12]. We see that, with both experimental observations and quark model calculations, all this kind of $q\bar{q}$ states can hardly have a total width of 20 MeV and, in particular, cannot have a partial decay width of the order of several hundreds keV to $\pi\pi$ or $K\bar{K}$, as observed for $\xi(2230)$. Therefore, as a result of the observation of small partial widths of $\xi \to \pi\pi, K\bar{K}$, we may conclude that the $\xi(2230)$ cannot be a conventional $q\bar{q}$ meson.

The copiously production in radiative J/ψ decay would disfavor the interpretation of a multi-quark state such as a $\Lambda\bar{\Lambda}$ bound state, a 4-quark state, etc. The production rate of $\xi(2230)$ could be only smaller than η_c and $\eta'(958)$, but larger than or as large as $\iota(1440)$,$\theta(1710)$,$f_4(2050)$,$f_2(1270)$ and $f_2'(1525)$. Thus $\xi(2230)$ is even more copiously produced than some well established conventional $q\bar{q}$ mesons such as $f_2(1270)$ and $f_2'(1525)$. As for multiquark states, according to the naive quark pair counting rule, they are usually expected to have smaller production rates than the corresponding $q\bar{q}$ states, since the creation of more quark pairs is needed for multiquark state production. Most naturally, the rich production of ξ in radiative J/ψ decays will imply that the $\xi(2230)$ is likely to be a glueball or a $q\bar{q}g$ hybrid state, but the former should have an even larger

production rate than the latter. As for hybrid interpretation, the width of a hybrid should not be so narrow since its decay is not totally OZI suppressed (with only one gluon converted into a quark pair), thus it would face much trouble in explaining the narrow width of $\xi(2230)$ (esp. the partial widths $\Gamma_{\pi\pi}$ and Γ_{KK}).

Finally, let's consider the glueball interpretation. So far, the gluball interpretation has no conflict with all the properties of $\xi(2230)$.

The mesonic decay of glueballs is determined by their flavor SU(3) singlet nature. With phase space factors removed, glueballs are naively expected to couple equally to all flavors. Since there has been no glueball confirmed by expriments, the best way looking into the flavor symmetry should be to study the decay processes which proceed through a two gluon intermediate state[10]. Fortunetly, there are a lot of experimets which have already studied such processes as the decays of charmonium family. One example is, the two gluon system in radiative J/ψ decays is an SU(3) singlet. This predicts[15] the ratio R=$\Gamma(J/\psi \rightarrow \gamma f_2'(1525))/\Gamma(J/\psi \rightarrow \gamma f_2(1270))$ = 0.45, if phace-space corrections are considered. The experimental result R = 0.46 ± 0.07[12] is in good agreement with the SU(3) singlet prediction. Other examples are that both χ_{c0} and χ_{c2} show flavor-symmetric decay behavior in their mesonic decays[12]. We believe the observed flavor-symmetry pattern of charmoniun decays does lend strong support to the conjecture that the glueball decays should be flavor-symmetric.

The copious production in radiative J/ψ decay is just the expectation for a glueball if we naively count the vertex of Feynman Diagram. The production rate of a glueball is of the order $\alpha\alpha_s^2$ while the production rate of a conventional $q\bar{q}$ meson is of the order $\alpha\alpha_s^4$. So a glueball could be easier produced than a conventional $q\bar{q}$ meson with the same J^{PC}.

The narrow width is also naively expected by conventional understanding of glueballs since their dacay to $q\bar{q}$ state is OZI suppressed and the suppression only acts at one vertex because of the absence of the initial $q\bar{q}$ annihilation for a glueball decay[16] . For example, the narrow width of $\xi(2230)$ can be easily explained by naive estimation that the width of a glueball Γ_G is about $\sqrt{\Gamma_{f_2(1270)}\Gamma_{\chi_{c2}}}$, i.e., about 10-50 MeV.

It is not surprising that the branching ratio Br($\xi \rightarrow K^+K^-$) and Br($\xi \rightarrow \pi^+\pi^-$) are smaller than 2% (consequently, $\Gamma_{\pi^+\pi^-}$ and $\Gamma_{K^+K^-}$ are smaller than 400 keV) for a glueball[10]. From the knowledge [12] about the hadronic decays of J/ψ,η_c, χ_{c0} and χ_{c2} which proceed through pure gluon intermediate state the same as glueball decays, it may be naively expected that another possible feature of the glueball decay is that the glueballs probably have more decay modes than conventional $q\bar{q}$ states. A $q\bar{q}$ meson decay occurs when the color flux tube formed by q and $\bar{q}$ is broken at large distances by the creation of new quark pairs (the OZI allowed decay); whereas a glueball decay proceeds via the gluon hadronization. There are more possibilities and combinations for the gluon fragmentation and hadronization than for the quark pair creation in a color flux tube. Therefore, a glueball may have more decay modes than a $q\bar{q}$ meson, and hence have smaller branching ratios to many final states. In this connections, for $\xi(2230)$ the observed flavor-symmetric decays to $\pi\pi$, $K\bar{K}$ and the smallness of these decay branching ratios

seem to favor the assignment that the $\xi(2230)$ is a glueball.

Since the observed $\pi\pi, K\bar{K}, p\bar{p}$ are expected to be, according the above discussion, only a small portion of the decay modes of ξ, searches for more decay modes of $\xi(2230)$ may be important. A systematical test of the flavor-symmetric nature in the decays will be meaningful for the glueball interpretation of ξ. We have noticed that the $p\bar{p}, \pi\pi$ and $K\bar{K}$ decay modes of a particle are the easiest tagged modes with high efficiency and low background for the BES detector. Other decay modes, such as $\eta\eta$, $\eta\eta'$,$\eta'\eta'$, $\rho\rho$, K^*K^*, $\omega\omega$, $\phi\phi$, $\pi\pi\pi\pi$, $\pi\pi KK$, etc., may suffer from either too low detecting efficiency or too large backgrounds or both of them. Anyway, we are interested in the results on such decay modes from BES or other experiments.

It is interesting to note that a comprehensive lattice study of SU(3) glueballs by the UKQCD Collaboration suggests the mass of the 2^{++} glueball be 2270 ± 100 MeV [17]. Then in the connection to the mass of $\xi(2230)$ and its glueball interpretation, it might be suggested that the spin-parity of ξ should be 2^{++}. We hope the BES experiments will collect more statistics of J/ψ data to obtain more definite result of the spin-parity of $\xi(2230)$ after the BES detector upgrade.

In summary, we believe that the recent results reported by BES is very encouraging in the identification of the puzzling state $\xi(2230)$. With both the BES and the PS185 experiments, this particle is found to have striking features that it has flavor- symmetric couplings to $\pi\pi$ and $K\bar{K}$, a large production rate in radiative J/ψ decays and very narrow partial decay widths to $\pi\pi$ and $K\bar{K}$. The $q\bar{q}$ model, multiquark model and hybrid model would face many difficulties in explaining the special properties of $\xi(2230)$. On the contrary, the glueball interpretation can naturally explain all of them. Therefore, these features would strongly favor the glueball interpretation of $\xi(2230)$.

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